NASA TN D-36

7N-05
194262
248

NASA TN D-36

TECHNICAL NOTE

D-36

ANALYSIS OF ACCELERATION, AIRSPEED, AND GUST-VELOCITY DATA FROM A FOUR-ENGINE TURBOPROP TRANSPORT OPERATING OVER THE EASTERN UNITED STATES

By Martin R. Copp and Mary W. Fetner

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON September 1959

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-36

ANALYSIS OF ACCELERATION, AIRSPEED, AND GUST-VELOCITY DATA FROM A FOUR-ENGINE TURBOPROP TRANSPORT OPERATING OVER THE EASTERN UNITED STATES

By Martin R. Copp and Mary W. Fetner

SUMMARY

Airspeed, altitude, and acceleration data obtained with an NASA (formerly NACA) VGH recorder installed in a four-engine turboprop transport operating over the Eastern United States were evaluated to determine the magnitude and frequency of occurrence of gust velocities and gust and maneuver accelerations. The results obtained were then compared with the results previously obtained from two long-haul operations utilizing transports equipped with four piston-type engines and flown over essentially similar routes.

The gust and gust-load experiences for the turboprop operation were essentially similar to those for the piston-engine operations. In addition, the results indicated that maneuver-acceleration histories for the turboprop operation were similar to those for piston-engine operations previously sampled. The turboprop transport was flown during cruise conditions at a higher percentage of its design cruising speed than were the piston-engine transports.

INTRODUCTION

Beginning about 1932, a continuing study of the magnitude and frequency of occurrence of gusts, gust accelerations, and maneuver accelerations experienced by transport airplanes in routine operations has been made. During this time, commercial airline operations have been systematically sampled in order to obtain as wide a coverage as possible with regard to airplane types, operators, and geographical location of routes. Assessments of the effects of these variables on the gust and load histories and operating practices of the operations sampled have then been made. With the introduction of turbine-powered transports, it might be expected that the operating practices and, therefore, loads histories would change because of differences in the characteristics of the new airplanes and the current piston-engine airplanes.

In order to obtain statistical information on the gust loads and operating practices of these new airplane types, the National Aeronautics and Space Administration has initiated a program with the cooperation of the airlines to install NASA (formerly NACA) V-G and VGH recorders in several of their turbine-powered transports. The present paper presents an analysis of the initial sample of VGH data obtained from a four-engine turboprop transport operating over the eastern portion of the United States. The gust and load histories and operating practices of the turboprop transport are compared with those for two long-haul operations utilizing transports equipped with four piston-type engines and flown over essentially similar routes (ref. 1 and operation H-VIII of ref. 2). L450

INSTRUMENTATION AND SCOPE OF DATA

The data were collected with an NASA (formerly NACA) VGH recorder which obtains a continuous record of the airplane's indicated airspeed, pressure altitude, and normal acceleration for use in a study of the airplane's load history and its associated operating practices. A detailed description of the recorder is given in reference 3.

The present data were obtained from routes flown over the eastern portion of the United States from June 1957 to September 1958. VGH data representing 1857.5 hours of flight were obtained; this number included 19.3 hours spent in check flights. A total of 1,347 operational flights were made during the record-collection period with an average flight duration of 1.36 hours. Cruising altitudes of these flights ranged from about 5,000 feet to 24,000 feet.

The characteristics of the airplane used in evaluating the VGH records and analyzing the data are as follows:

Design gross weight, W, lb	63,000
Average operating weight, lb	53,500
Wing area, S, sq ft	963
Span, b, ft	93.7
Aspect ratio, A	9.1
Mean geometric chord, $\bar{c}$, ft	10.3
Slope of lift curve, per radian $\left(\text{computed from } \frac{6A}{A + 2};\right.$ see ref. 4$\left.\right)$	4.92
Design speed for maximum gust intensity (indicated), V_B, knots	166
Design cruising speed (indicated), V_C, knots	238

Never-exceed speed (indicated), V_{NE}, knots 272

Normal acceleration corresponding to the limit-gust-load-factor increment, $a_{n,LLF}$, g units (computed according to ref. 5) 1.31

The pertinent operational data and characteristics of the turboprop transport and the two long-haul airplanes hereinafter referred to as piston-engine transports are given in table I. (The operational data of ref. 1 and operation H-VIII of ref. 2 have been designated operations A and B, respectively.) In addition, flight profiles based on average values of indicated airspeed, pressure altitude, and length of flight are shown in figure 1 for the three operations. The average values of the quantities plotted were obtained from total operational data samples (approximately 1,838 hours of VGH data for the turboprop transport and 1,038 and 1,721 hours for operations A and B, respectively) and, therefore, do not represent specific flights.

EVALUATION OF DATA AND RESULTS

Gust Accelerations

The VGH records were evaluated in accordance with the procedures described in detail in reference 6. Basically, the evaluation consisted of reading positive and negative gust acceleration peaks a_n above a threshold of ±0.2g by using the steady-flight position of the acceleration trace as a reference. These procedures differed slightly from previous investigations (which used an evaluation threshold of ±0.3g) in order that a count of the smaller gust accelerations could be made. These data were formed into combined (positive and negative) frequency distributions of gust accelerations and are given in table II for class intervals of 0.1 g for each flight condition (climb, en route, and descent), as well as for the total sample. The number of flight hours and statute flight miles represented by each distribution are also given in table II, as well as the average indicated airspeeds for each phase of the operation and the average number of accelerations equal to or greater than ±0.2g experienced per mile of flight. The total acceleration distribution of table II is shown in figure 2 in terms of the average number of accelerations above a given value experienced per mile of flight. The ordinate values were obtained by progressively summing (starting with the frequency of the largest acceleration) the total frequency distribution of table II and then dividing each sum by the total flight distance represented by the data. Similar distributions for operations A and B are also given in figure 2.

Since the characteristics of the airplanes used in operations A and B were different from those of the turboprop transport, the accelerations cannot be used as a measure of the relative load histories of the various operations. In order to make a more appropriate comparison, the acceleration distributions of figure 2 are presented in figure 3 as a ratio of the measured normal-acceleration increment a_n to the normal-acceleration increment corresponding to the computed limit-gust-load-factor increment $a_{n,LLF}$ of the particular transports used in each of the operations. The ordinate scale, as in figure 2, is in terms of the frequency of occurrences greater than a given value per mile of flight. The values of $a_{n,LLF}$ used in obtaining figure 3 are given in table I. L 4 5 0

Maneuver Accelerations

Operational- and check-flight-maneuver accelerations were evaluated by reading the appropriate peak deflections of the acceleration trace greater than a value of ±0.1g. The procedures used to evaluate maneuver accelerations have been described in detail in previous papers. (See, for example, ref. 7.)

Frequency distributions of positive and negative operational- and check-flight-maneuver accelerations are given in table III. The total number of record hours, the amount of time actually spent in check flights, and the flight miles represented by the distributions are also shown in this table.

The frequency of occurrence of positive and negative operational- and check-flight-maneuver accelerations for the turboprop operation are plotted in figure 4. For comparison, positive and negative frequency distributions of gust accelerations are shown also in figure 4 for the turboprop transport.

Gust Velocities

Derived gust velocities U_{de} were calculated for each gust acceleration peak by means of the revised gust-load formula of reference 8:

$$U_{de} = \frac{2Wa_n}{K_g \rho_o V_e mS}$$

where

U_{de}	derived gust velocity, fps
W	airplane weight, lb

a_n normal acceleration, g units

K_g gust factor

ρ_o air density at sea level, slugs/cu ft

V_e equivalent airspeed, fps

m slope of lift curve per radian

S wing area, sq ft

The average airplane operating weight of 53,500 lbs was used in determining the values of K_g and in calculating the gust velocities. The resulting combined (positive and negative) frequency distributions of derived gust velocities for the turboprop operation are listed in table IV in class intervals of 4 feet per second for each 5,000-foot pressure-altitude interval and for the total operation. The number of flight hours, flight miles, and the average number of gust velocities equal to or greater than 4 feet per second encountered per mile of flight for each altitude interval and for the total operation are also given in table IV.

The frequency of occurrence of gust velocities for the complete operation is plotted in figure 5. Gust-velocity frequency distributions for operations A and B are shown in figure 5 for comparison. Due to incomplete frequency counts of gust velocities less than 12 feet per second for operations A and B, the frequency of occurrence of gust velocities less than 12 feet per second was omitted from figure 5 for the three operations shown.

Operating Airspeeds

The indicated airspeed and pressure altitude were read from the VGH records for each 1-minute interval of flight in order to obtain average airspeeds $\overline{V}$ and pressure altitudes for the climb, en route, and descent flight conditions and for the total data sample obtained. Average airspeeds in rough air were also computed to determine whether significant airspeed reductions were made upon encountering turbulence. These values were calculated from the 1-minute airspeed readings which were read during rough-air conditions. For this evaluation, any portion of the VGH record was considered to represent rough air if the acceleration trace contained gust-acceleration peaks of at least ±0.2g. Average airspeed values for the overall operation and for the rough-air phases of the operation are listed in table I as fractions of V_C for the climb, en route, and descent flight conditions. Similar airspeed ratios for operations A and B are shown also in table I. For operations A and B, however, airspeeds in rough air were defined as airspeeds at which gust accelerations greater than ±0.3g were encountered.

RELIABILITY OF RESULTS

Instrument errors in the VGH recorder and installation errors have been discussed in detail in reference 9. These errors are not considered of sufficient magnitude to affect the reliability of the present results. Reading errors, however, can affect the reliability of the results as indicated in reference 10. The effect of these errors tends to diminish as the data sample increases up to about 1,000 hours after which it remains essentially constant. For the present operation (1857.5 hours), it is estimated that the acceleration and derived-gust-velocity values for the total operation are reliable to within ±15 percent for a given frequency of occurrence at the lower values. The reliability of the distributions for 5,000-foot altitude intervals and for the climb, en route, and descent flight conditions is somewhat less due to the smaller amount of data in each distribution.

L450

The reliability of the gust accelerations and derived gust velocities for operation A (operation F-VI of ref. 2; 1,038 hours) and operation B (operation H-VIII of ref. 2; 1,721 hours) is estimated also to be about ±15 percent.

In addition to reading errors, sampling variations may also affect the reliability of the VGH data. Estimates of the statistical reliability of the total data sample were made, based on the method described in reference 6, and indicated that the total distributions of gust acceleration and gust velocity (figs. 2 and 5) are statistically reliable within a factor of about 2 on the ordinate scale at the smaller values and within a factor of about 3 at the higher values. Similar estimates were determined for operations A and B.

DISCUSSION

Gust Accelerations and Gust-Load Histories

Comparison of the curves of figure 2 indicates that for the three operations shown no differences are apparent in the frequency of occurrence of gust accelerations. This might be expected since the routes flown and operating characteristics of the airplanes as noted in figure 1 are essentially similar. It should be noted, however, that a turboprop airplane is capable of operating efficiently at other airspeeds and altitudes and other operations may differ significantly from the one sampled.

A breakdown of the VGH gust-acceleration data into distributions for the climb, en route, and descent conditions indicated that the greatest number of gust accelerations $\geqq 0.2g$ per mile of flight were encountered during the descent condition and the least number during the en route or cruise condition (table II). These results are in general agreement with previous investigations. (See, for example, ref. 6.)

L
4
5
0

The curves of figure 3 indicate that the load history (based on exceeding given fractions of the computed limit-gust-load-factor increment) for the turboprop operation is approximately the same as for operation A and slightly more severe than for operation B. However, the differences as shown in figure 3 do not appear to be significant.

Maneuver Accelerations

Figure 4 indicates that positive and negative frequency distributions of gust accelerations as well as operational- and check-flight-maneuver accelerations are approximately symmetrical for the turboprop operations and that the maximum positive gust and check-flight-maneuver accelerations were larger than the negative values.

The results shown in figure 4 are in general agreement with previous investigations (refs. 6, 7, and 11) which indicated that generally, for the smaller acceleration values, the gust accelerations are more frequent than the maneuver accelerations. For some operations (ref. 6), however, the frequency of the larger maneuver accelerations (1.0g or greater) may equal the frequency of the gust accelerations. Such a tendency may be noted for the positive maneuver accelerations (fig. 4) from the present operation. It is felt, therefore, that the relative contribution of the maneuver accelerations to the total flight load history is probably dependent upon individual piloting techniques as well as different operational procedures used by the various airlines.

Gust Velocities

Figure 5 shows that essentially no differences exist among the frequencies of occurrence of gust velocities for the three operations. The similarity of the gust distributions would normally be expected since most of the VGH data for the three operations were obtained over essentially the same portion of the United States at approximately the same altitudes.

A further breakdown of the gust-velocity data was made (table IV) to determine the variation of gust frequency with pressure altitude for the altitude range covered by the turboprop operation. It was found that a fairly orderly decrease in gust frequency with increasing pressure altitude existed from sea level to about 20,000 feet. For the 20,000- to 25,000-foot altitude interval, however, no further reductions were observed. This may be due to the comparatively small amount of data obtained for altitudes above 20,000 feet. (See table IV.) Additional data for the higher altitudes are needed before any definite trends can be established for airline operations although references 12 and 13 indicate that a decrease in gust frequency should continue to much higher altitudes.

L
4
5
0

Airspeed Practices

An examination of table I indicates that the turboprop transport was flown during en route or cruise conditions at a higher percentage of its design cruising speed V_C than were the piston-engine airplanes. In addition, reductions of 3 percent and 7 percent, respectively, of V_C are apparent for the cruise and descent conditions in turbulent air for the turboprop operation. For the piston-engine airplanes, however, no reductions in the average airspeeds upon encountering turbulence are indicated in table I.

Portions of VGH records showing substantial decreases in airspeed upon encountering turbulence are presented in figure 6 for the turboprop operation. The VGH records for the piston-engine airplanes indicated that slowdown procedures were also practiced to some extent. However, it appeared, in general, that slowdown procedures upon encountering turbulence were practiced more extensively for the turboprop operation than for the two piston-engine operations. This may be due to a practice of the piston-engine-transport operators of not reducing the airspeed unless turbulence more severe than that represented in the present data is encountered.

CONCLUSIONS

An analysis of VGH data obtained from a four-engine turboprop-transport operation has been made. A comparison of the results with those of two long-haul operations utilizing transports equipped with four piston-type engines and flown over essentially similar routes has indicated the following results:

1. The frequency of occurrence of gust accelerations and gust velocities of a given value were similar for the three operations.

2. Given fractions of the limit-gust-load-factor increment $a_n/a_{n,LLF}$ occurred as frequently for the turboprop operation as for the piston-engine operations.

3. Maneuver-acceleration histories for the turboprop operation were similar to those for piston-engine operations previously sampled.

4. The turboprop airplane was flown during cruise conditions at a higher percentage of its design cruising speed V_C than were the piston-engine transports.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., April 28, 1959.

REFERENCES

1. Coleman, Thomas L., and Fetner, Mary W.: An Analysis of Acceleration, Airspeed, and Gust-Velocity Data From a Four-Engine Transport Airplane in Operations on an Eastern United States Route. NACA TN 3483, 1955.

2. Walker, Walter G., and Copp, Martin R.: Summary of VGH and V-G Data Obtained From Piston-Engine Transport Airplanes From 1947 to 1958. NASA TN D-29, 1959.

3. Richardson, Norman R.: NACA VGH Recorder. NACA TN 2265, 1951.

4. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Supersedes NACA TN 1976.)

5. Anon.: Airplane Airworthiness - Transport Categories. Pt. 4b of Civil Air Regulations, Civil Aero. Board, U. S. Dept. Commerce, Dec. 31, 1953.

6. Copp, Martin R., and Coleman, Thomas L.: An Analysis of Acceleration, Airspeed, and Gust-Velocity Data From One Type of Four-Engine Transport Airplane Operated Over Two Domestic Routes. NACA TN 3475, 1955.

7. Coleman, Thomas L., and Copp, Martin R.: Maneuver Accelerations Experienced by Five Types of Commercial Transport Airplanes During Routine Operations. NACA TN 3086, 1954.

8. Pratt, Kermit G., and Walker, Walter G.: A Revised Gust-Load Formula and a Re-evaluation of V-G Data Taken on Civil Transport Airplanes From 1933 to 1950. NACA Rep. 1206, 1954. (Supersedes NACA TN's 2964 by Kermit G. Pratt and 3041 by Walter G. Walker.)

9. Press, Harry, and McDougal, Robert L.: The Gust and Gust-Load Experience of a Twin-Engine Low-Altitude Transport Airplane in Operation on a Northern Transcontinental Route. NACA TN 2663, 1952.

10. Copp, Martin R., and Walker, Walter G.: Analysis of Operational Airline Data To Show the Effects of Airborne Weather Radar on the Gust Loads and Operating Practices of Twin-Engine Short-Haul Transport Airplanes. NACA TN 4129, 1957.

11. Engel, Jerome N., and Copp, Martin R.: Analysis of Acceleration, Airspeed, and Gust-Velocity Data From a Four-Engine Transport Airplane Operating Over a Northwestern United States-Alaska Route. NASA MEMO 1-17-59L, 1959.

L
4
5
0

12. McDougal, Robert L., Coleman, Thomas L., and Smith, Philip L.: The Variation of Atmospheric Turbulence With Altitude and Its Effect on Airplane Gust Loads. NACA RM L53G15a, 1953.

13. Coleman, Thomas L., and Coe, Emilie C.: Airplane Measurements of Atmospheric Turbulence for Altitudes Between 20,000 and 55,000 Feet Over the Western Part of the United States. NACA RM L57G02, 1957.

TABLE I

OPERATIONAL DATA

Operation	Design gross weight, lb	Wing loading, lb/sq ft	$a_{n,LLF}$	Average cruising altitude, ft	Average length of flight, hr	Cruising speed (indicated), V_C, knots	$\overline{V}_{overall}/V_C$			$\overline{V}_{rough\ air}/V_C$		
							Climb	En route	Descent	Climb	En route	Descent
Turboprop transport (present)	63,000	65.4	1.31	14,100	1.36	238	0.70	0.88	0.85	0.71	0.85	0.78
A (ref. 1)	107,000	64.8	1.31	12,000	1.7	235	.66	.85	.89	.69	.86	.88
B (operation H-VIII of ref. 2)	93,200	63.6	1.47	14,300	1.86	261	.61	.73	.77	.65	.74	.77

TABLE II

FREQUENCY DISTRIBUTIONS OF GUST ACCELERATIONS BY FLIGHT CONDITION

Normal acceleration (positive or negative), a_n, g units	Frequency of occurrence for -			Total frequency of occurrence
	Climb	En route	Descent	
0.2 to 0.3	5,734	6,073	13,378	25,185
.3 to .4	628	983	1,874	3,485
.4 to .5	141	301	448	890
.5 to .6	38	105	120	263
.6 to .7	4	38	38	80
.7 to .8	1	14	10	25
.8 to .9	-----	7	6	13
.9 to 1.0	-----	3	2	5
1.0 to 1.1	-----	1	1	2
1.1 to 1.2	-----	-----	------	------
1.2 to 1.3	-----	1	------	1
1.3 to 1.4	-----	-----	1	1
Total	6,546	7,526	15,878	29,950
Flight hours	316.3	1071.7	450.2	1838.2
Flight miles	6.9×10^4	32.1×10^4	11.7×10^4	50.7×10^4
Average indicated airspeed, knots	167.4	209.8	202.3	200.6
Average number of accelerations $\geqq \pm 0.2g$ per mile	0.95×10^{-1}	0.23×10^{-1}	1.36×10^{-1}	0.59×10^{-1}

L
4
5
0

TABLE III

FREQUENCY DISTRIBUTIONS OF MANEUVER ACCELERATIONS

(a) Operational maneuvers

Normal acceleration, a_n, g units	Frequency of occurrence
0.5 to 0.6	3
.4 to .5	21
.3 to .4	164
.2 to .3	915
.1 to .2	18,059
-.1 to -.2	15,775
-.2 to -.3	690
-.3 to -.4	90
-.4 to -.5	7
-.5 to -.6	1
Total	35,725
Flight hours . . .	1838.2
Flight miles . . .	50.7×10^4

(b) Check-flight maneuvers

Normal acceleration, a_n, g units	Frequency of occurrence
0.8 to 0.9	2
.7 to .8	1
.6 to .7	1
.5 to .6	3
.4 to .5	6
.3 to .4	29
.2 to .3	96
.1 to .2	892
-.1 to -.2	729
-.2 to -.3	54
-.3 to -.4	15
-.4 to -.5	1
Total	1,829
Flight hours . . .	1857.5
Time in check flights, hr . . .	19.3
Flight miles . . .	51.0×10^4

TABLE IV

FREQUENCY DISTRIBUTIONS OF DERIVED GUST VELOCITIES

Derived gust velocity (positive or negative), U_{de}, fps	Frequency of occurrence for -					Total frequency of occurrence
	0 to 5,000 ft	5,000 to 10,000 ft	10,000 to 15,000 ft	15,000 to 20,000 ft	20,000 to 25,000 ft	
4 to 8	800	391	284	114	3	1,592
8 to 12	11,827	4,059	2,494	1,579	175	20,134
12 to 16	5,248	624	384	150	41	6,447
16 to 20	749	247	161	35	13	1,205
20 to 24	199	84	64	5	11	363
24 to 28	54	36	33	1	6	130
28 to 32	22	13	9	-----	3	47
32 to 36	4	6	6	1	1	18
36 to 40	4	1	4	-----	1	10
40 to 44	------	1	1	-----	---	2
44 to 48	1	-----	1	-----	---	2
Total	18,908	5,462	3,441	1,885	254	29,950
Flight hours	298.1	373.1	681.7	437.8	47.5	1838.2
Flight miles	6.1×10^4	9.5×10^4	20.0×10^4	13.1×10^4	2.0×10^4	50.7×10^4
Average number of gusts $\geqq \pm 4$ fps per mile	3.10×10^{-1}	0.57×10^{-1}	0.17×10^{-1}	0.14×10^{-1}	0.13×10^{-1}	0.59×10^{-1}

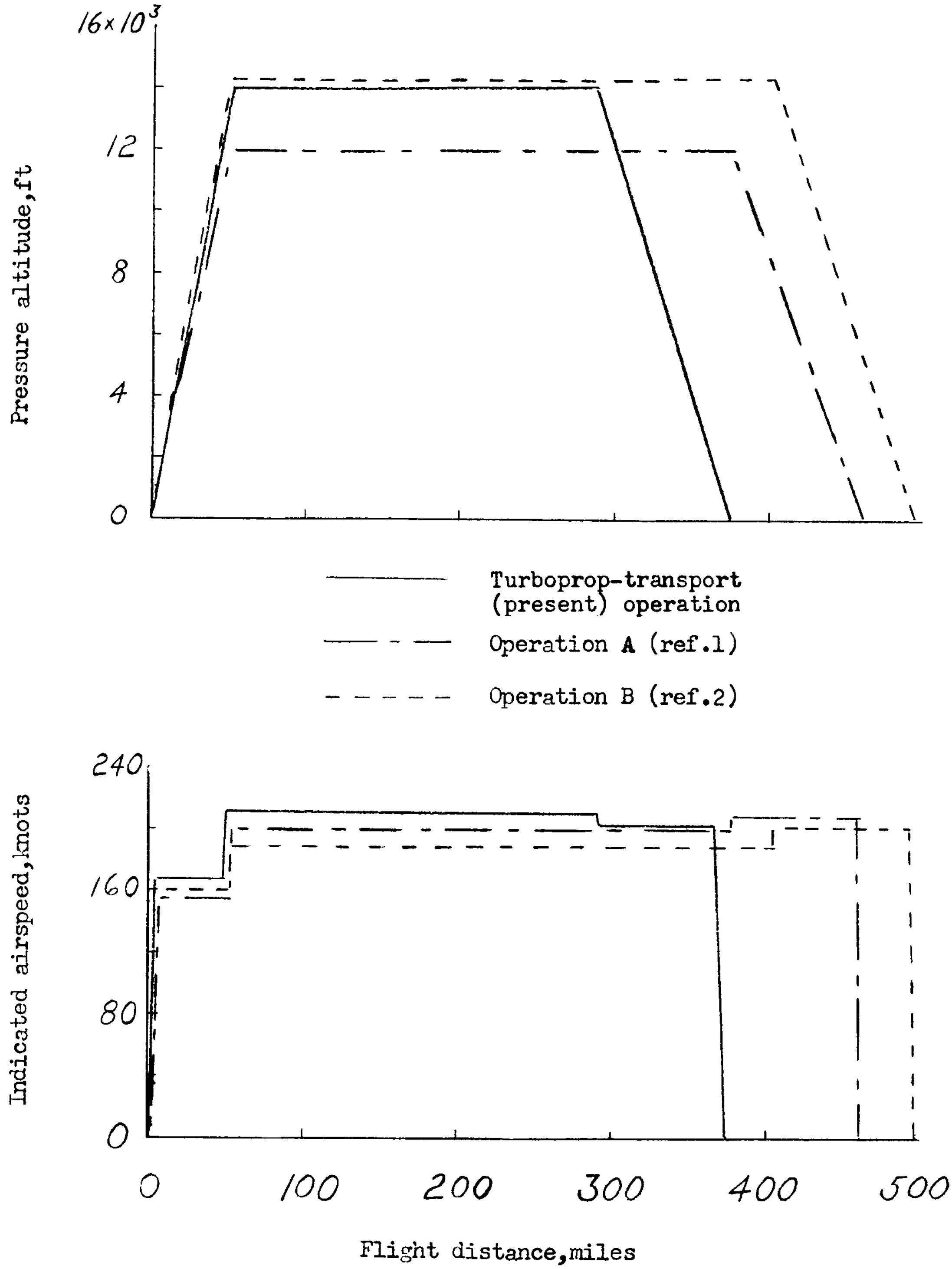

Figure 1.- Average flight profiles for three transport operations.

L-450

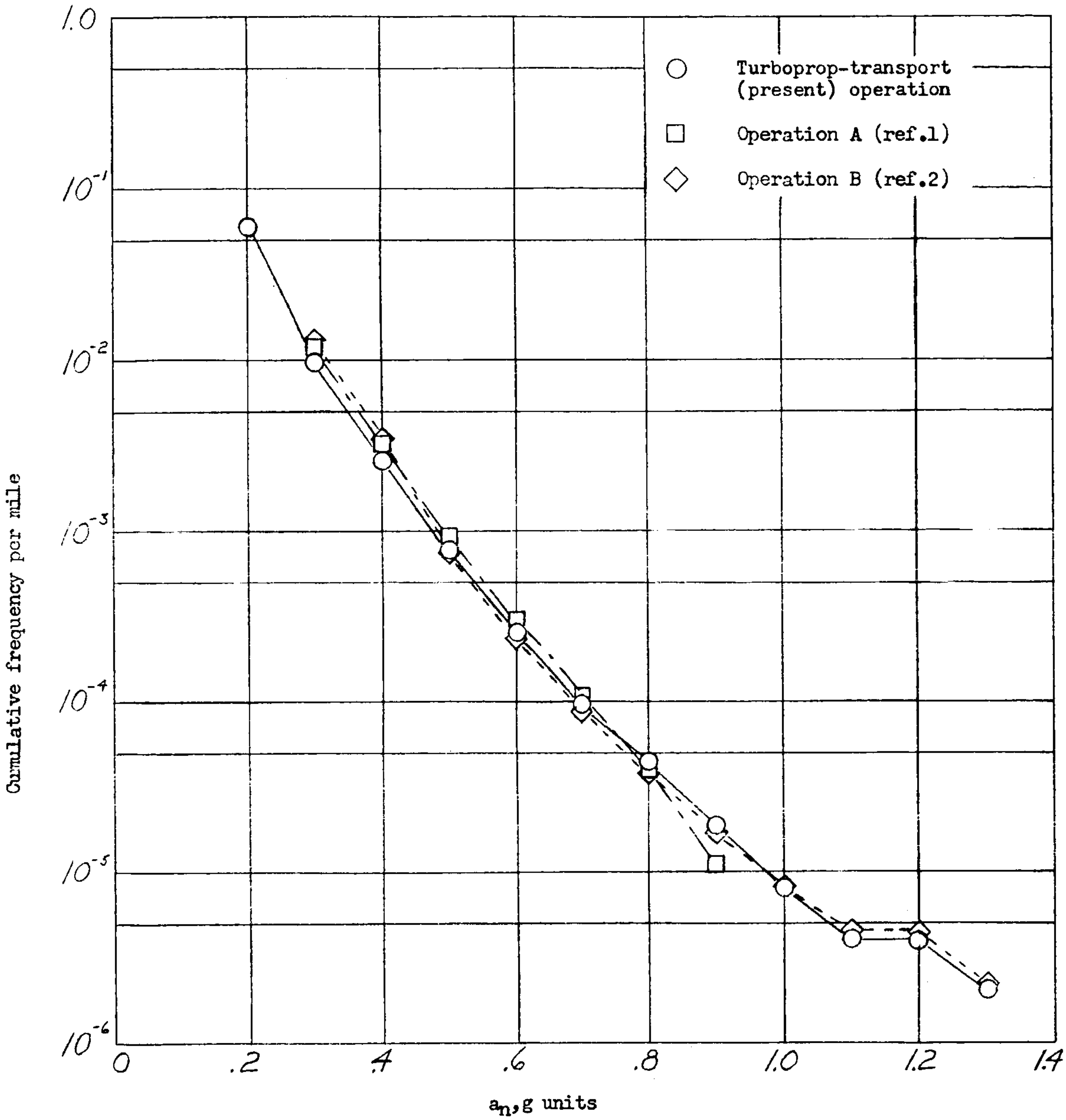

Figure 2.- Comparison of frequency of exceeding given values of gust acceleration per mile of flight for three transport operations.

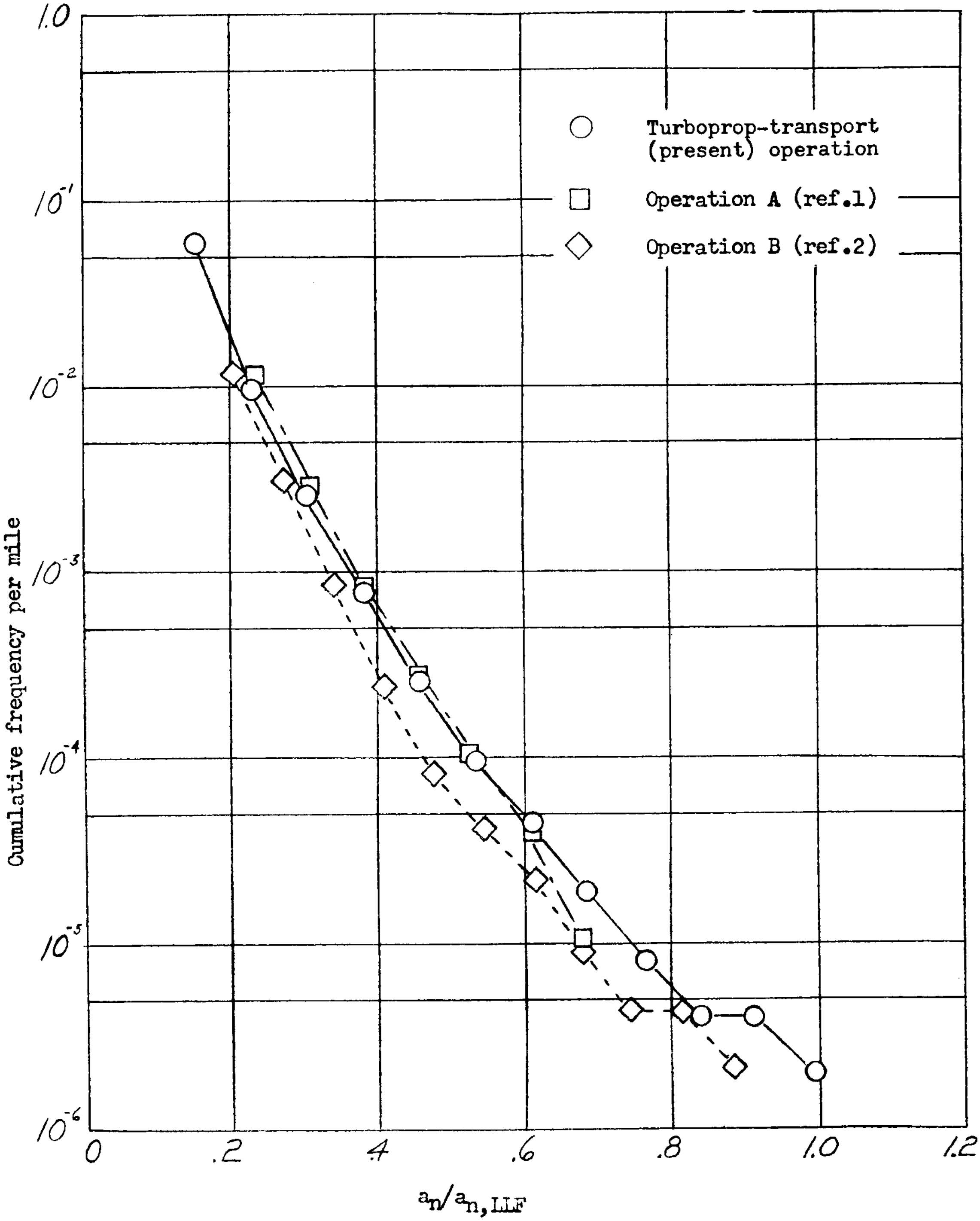

Figure 3.- Comparison of frequency of exceeding given values of $a_n/a_{n,LLF}$ for three transport operations.

L-450

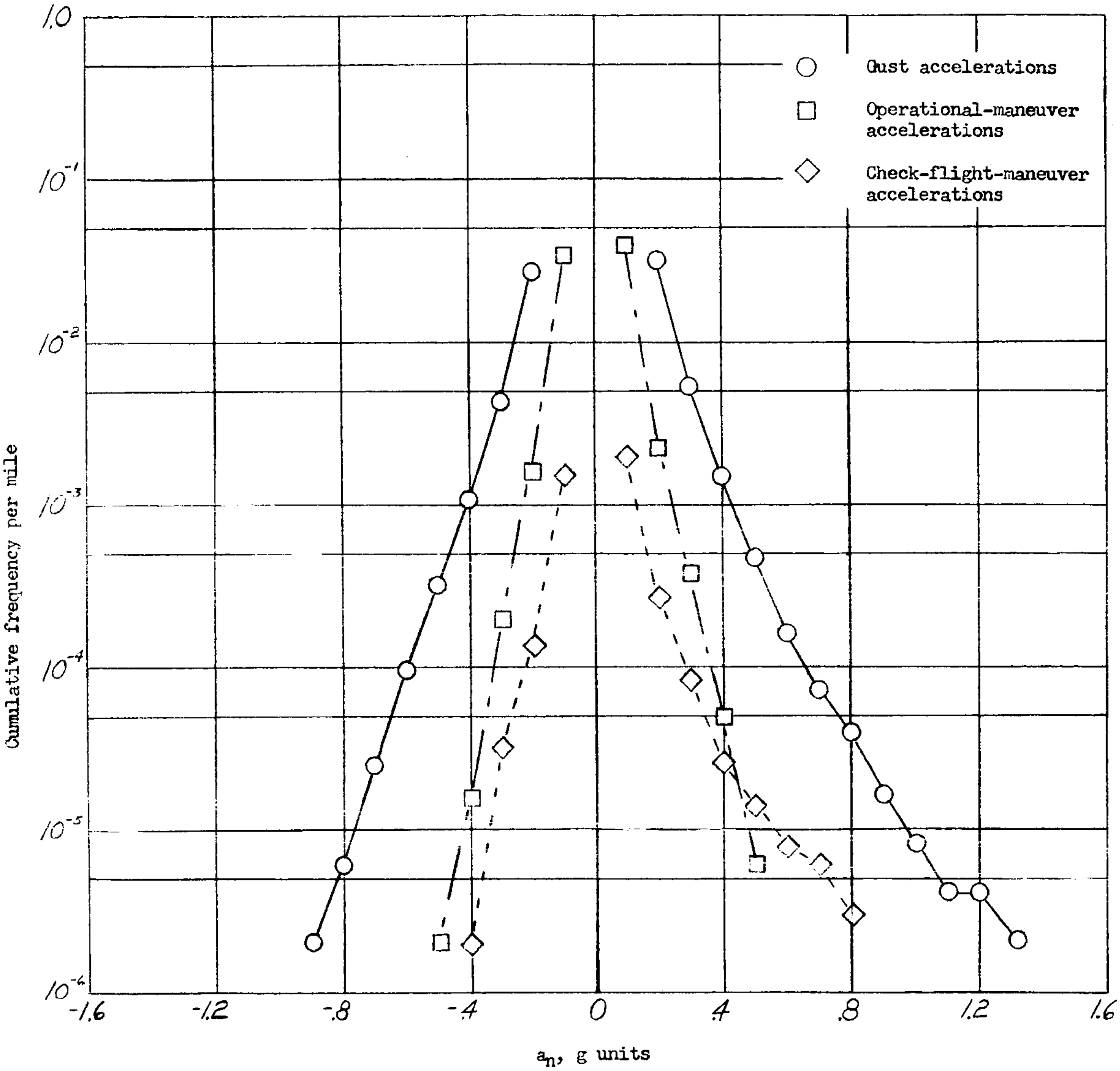

Figure 4.- Comparison of frequency of exceeding given values of gust and maneuver accelerations per mile of flight.

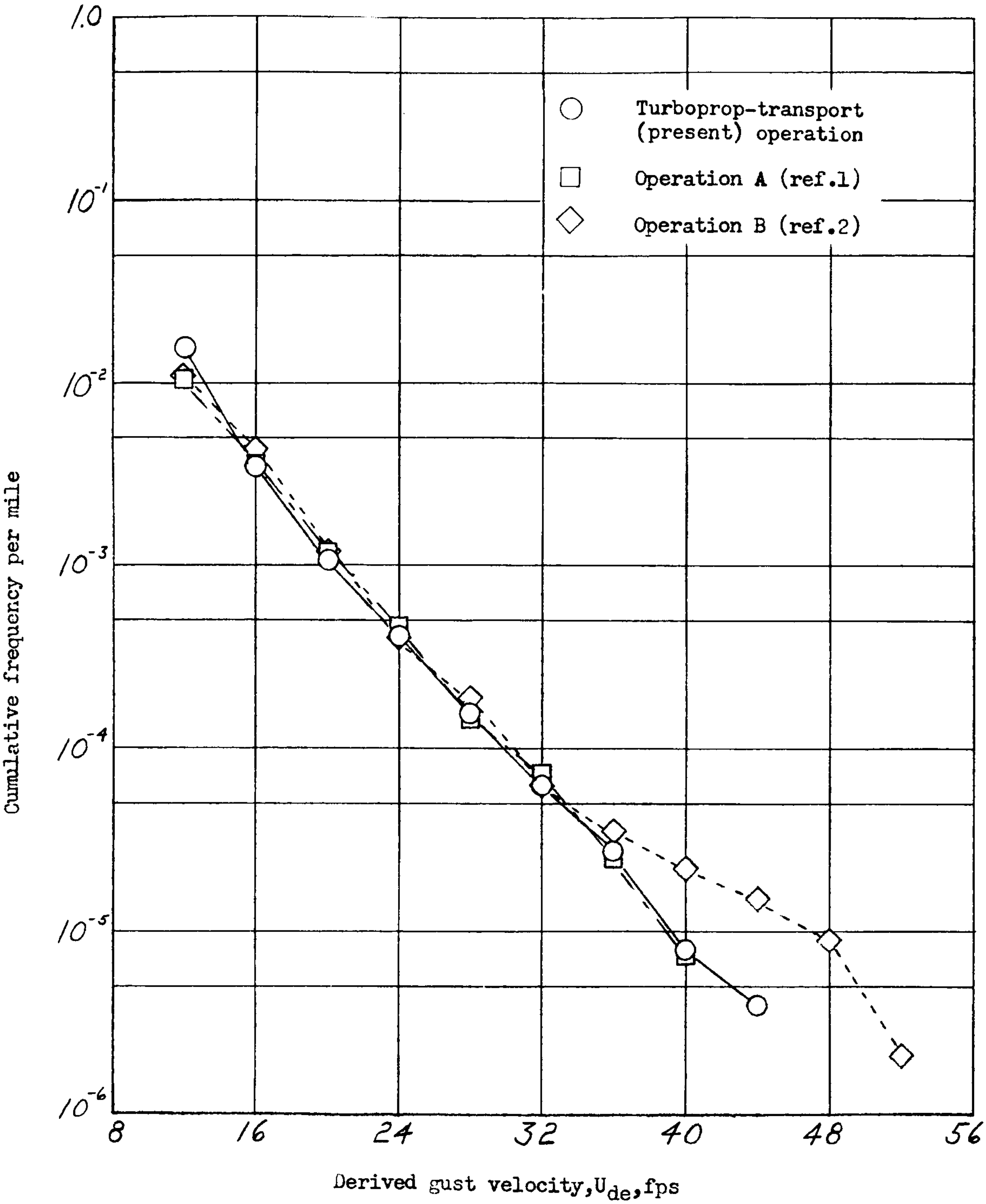

Figure 5.- Comparison of frequency of exceeding given values of derived gust velocity per mile of flight for three transport operations.

L-450

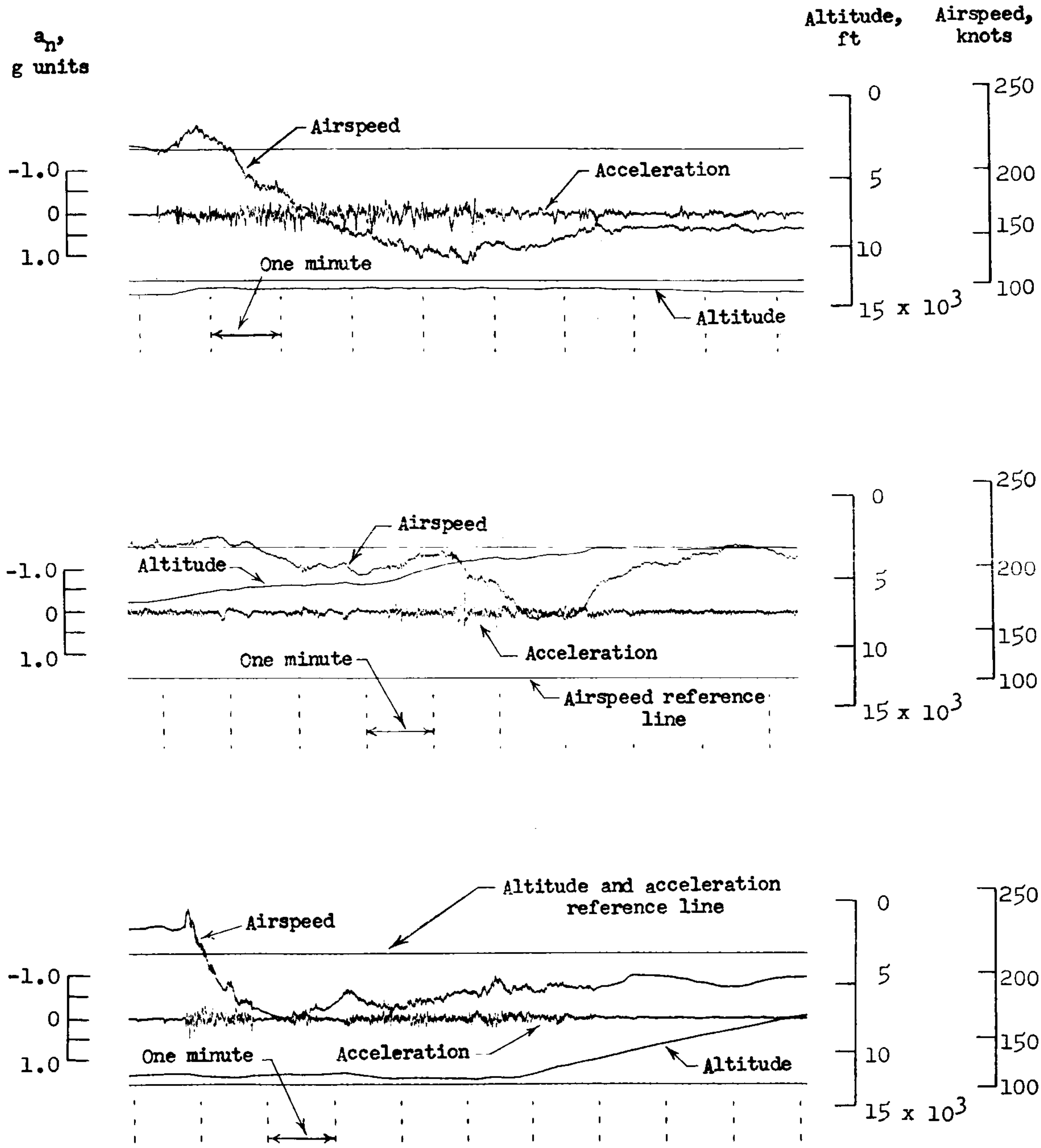

Figure 6.- VGH records indicating airspeed reductions upon encountering turbulence.